Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Separate-effect Test for Cooling Performance of PAFS(Passive Auxiliary Feedwater System)

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1. Introduction

APR+ (Advanced Power Reactor Plus) is a next generation nuclear power plant being developed in Korea. It adopts PAFS (Passive Auxiliary Feedwater System) for the steam generator (SG) instead of an active auxiliary feedwater system for the conventional nuclear power plant (NPP). It can replace the conventional active auxiliary feedwater system for the SG by a passive way.[1] It is composed of a steam-supply line, a condensation heat exchanger, a return-water line, and a PCCT (Passive Condensate Cooling Tank). When the water level in the SG becomes lower than 25% of the wide range of the water level transmitter during an accident situation, the actuation valve at the return-water line is open and then the natural convection flow of the PAFS can be made.

To validate a cooling performance of PAFS, separate effect test loop, which is named PASCAL (PAFS Condensing heat removal Assessment Loop) was constructed at KAERI (Korea Atomic Energy Research Institute)[2] for investigating the cooling capability of the condensation heat exchanger and the characteristic of the natural convection. This study focuses on the experimental study of the separate effect test with PASCAL facility. From the experimental results, two-phase flow phenomena in the condensation heat exchanger and PCCT are investigated for the verification of the design of PAFS.

2. Test Facility

PASCAL facility simulates a single tube among 240 tubes in the prototype, that is, the volumetric scaling ratio of the facility is 1/240. The volume of PCCT pool in the facility was also reduced to 1/240 of prototype. In order to conserve natural convection flow in PCCT, the height of the pool is determined to be same as that of the prototype. The length of PCCT in the PASCAL facility is 6.7m, which is a half of that of prototype, since the bundles are placed in two rows. So the width of PCCT was 0.112m, which is equivalent to 1/120 of that of prototype.

A steam generator in PASCAL facility plays a role in supplying saturated steam to the heat exchanger tube. An electrical heater in the steam generator provides a heat source which scaled down the heat transfer rate at U-tube surface in the prototype steam generator. To conserve a driving force of the natural convection in the loop, a distance between the mixture level in the steam generator and the heat exchanger tube was maintained to be equivalent to that of the prototype. The steam generator was connected to the heat exchanger tube with a steam-supply line and a return-water line. Figure 1 shows the schematic diagram of PASCAL facility.

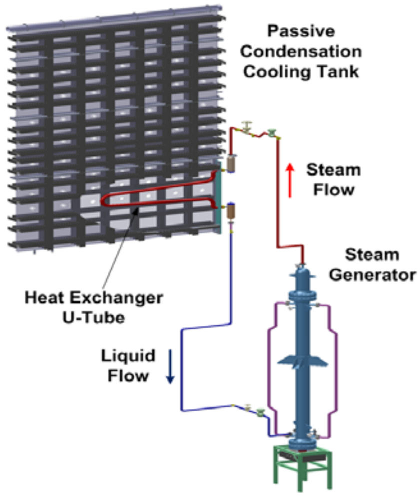

Fig. 1 Schematic diagram of PASCAL facility

3. Experimental Results

The separate effect test for validation of the cooling performance of the condensation heat exchanger was performed according to the maximum heat removal condition of PAFS. Since it is required for a single system of PAFS to remove 129.8 MW as a maximum heat removal rate, the test condition was determined according to the scaling ratio of the facility. Therefore, 550kW of thermal power was supplied in the steam generator heater. The pool water was maintained as the saturated state at an atmospheric pressure. When the pressure, temperature, and flow rate reached a steady state at the constant thermal power condition, the heat removal rate and the natural convection flow was measured.

Figure 2 compares the heat removal rate on the steady state at the continuous thermal power of the steam generator heater for the steady state of 300 seconds. In the system, the heat removal rate could be classified as listed in Table 1, which include the summation of surface heat transfer rate of the condensation heat exchanger(HR-Tube), the enthalpy decrease between the inlet and the outlet of the heat exchanger(HR-SS and HR-RW). The figure presents that the supplied thermal power is effectively removed by the heat transfer at the condensation heat exchanger emerged in PCCT.

Figures 3 and 4 show the pressure and temperature of the main loop, respectively. It is confirmed that the steady state condition was achieved when the pressure of the system reached 3.3 MPa and the steam temperature was 245℃ with the 550kW of thermal power. Considering that the heat exchanger of PAFS was designed to remove the decay heat at the steam condition of 7.4 MPa and 290℃, the experimental result proved that the current design of the condensation heat exchanger had an enough margin to cool down the reactor system without any active safety injection system.

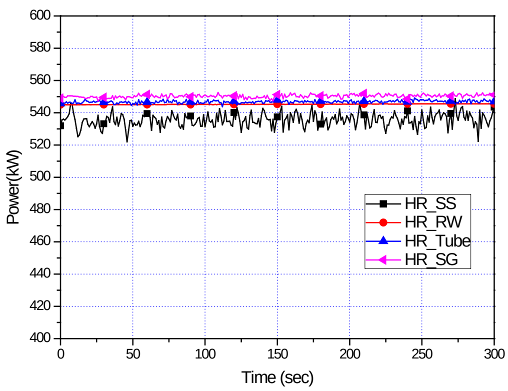

Fig. 2 Heat removal rate of PASCAL facility

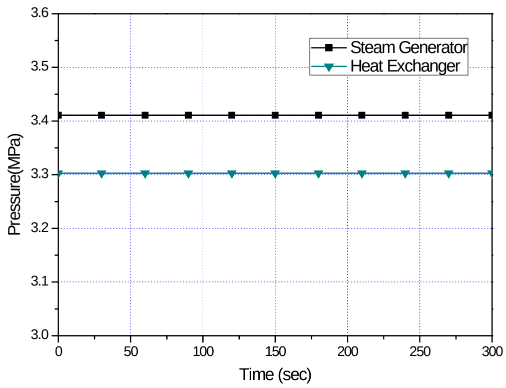

Fig. 3 System pressure in the steady-state experiment

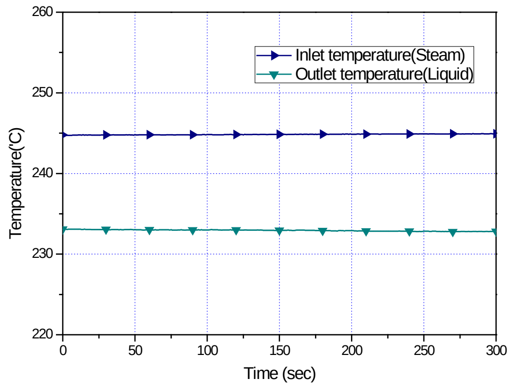

Fig. 4 Fluid temperature in the steady-state experiment

Table 1 Definition of heat removal rate

Notation	Description
HR-SG	Thermal power supplied by electrical heaters in SG
HR-Tube	Heat removal rate of condensation heat exchanger calculated from summation of wall heat transfer rate
HR-SS	Heat removal rate calculated from the flow rate in steam-supply line
HR-RW	Heat removal rate calculated from the flow rate in return-water line

4. Conclusion

The separate-effect test was performed in order to verify the cooling capability of the PAFS. In the experiment, the heat removal of a single tube heat exchanger and the natural convection in the loop were investigated. The test result proved that the current design of the condensation heat exchanger satisfied the requirement for cooling down the decay heat during an accident on the secondary system. Therefore, it is concluded that PAFS can replace a conventional active AFWS(Auxiliary Feedwater System) in APR+ nuclear power plant, utilizing the natural convection flow driven by the natural convection of two-phase flow.

ACKNOWLEDGMENTS

This research has been performed as a part of the nuclear R&D program supported by the Ministry of Knowledge Economy of the Korean government.

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